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TITLE: TURBULENCE

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TURBULENCE

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1. BRIEF DESCRIPTION OF THE WORK

Current theories for material mixing include multiphase interpenetration and single-field turbulence transport with large density variations. Neither approach by itself is adequate for current problem-solving needs, but in combination they offer tremendous opportunities for the analysis of complex material dynamics. Multiphase theory contributes the "ordered" jets or particulate trajectories that penetrate in wave-like fashion; turbulence transport superimposes the important nonlinear diffusive component to the mixing. Shear impedance and energy transport arise naturally in this combined analysis.

Two approaches for combining these theories are being investigated. One begins with multiphase flow and adds turbulence enhancement, the other is based on single-field turbulence transport with closure guidance from multiphase flow theory. This talk describes the principal world-wide activities in these developments, with emphasis on current scope of applicability, essential physical and mathematical properties and challenges, and the directions for future research. The discussion demonstrates a continuing need to compromise between theoretical completeness and tractability for the accurate and efficient numerical solution of practical problems. It shows, however, that there are not simple procedures for solving today's challenging problems involving the turbulent mixing of materials. The combination of multiphase flow and turbulence transport theories may appear formidable, but the employment of this powerful combination in our numerical investigations holds high promise of paying handsome dividends.

2. EXAMPLES

Numerous circumstances occur in nature for which instability, turbulence, and interpenetration are significant parts of the dynamics. Some examples are the following.

- Normal acceleration of a discontinuity in density can result in the unstable growth of perturbations, followed by mixing of the two materials. One of the most exciting and significant recent discoveries in the field of fluid dynamics is that the well-developed nonlinear phase of this process proceeds in a manner independent of the initial perturbations. Constant acceleration, for example, results in self-similar growth of the mix layer; single or multiple shock acceleration is followed by wave-like multiphase interpenetration plus diffusion-like turbulence transport of mass, momentum, and energy.
- Oblique intersection of a shock with a material interface results in material slip across the contact discontinuity and across the slip surface behind triple-shock intersection if Mach reflection occurs. Instability can lead to both material mixing and significant turbulent shear impedance.
- Radiation onto a homogeneous or composite material can eject or ablate material in flow patterns that again combine the multiphase interpenetration of jets or chunks with the turbulent diffusion of both heat and material.
- Deflagration (chemical burn) through grainy materials is a tremendous challenge to our combined equations for multiphase flow and turbulence transport; even turbulent flame-front propagation through homogeneous flammable-gas mixtures is far from being understood.

These are just a sampling of the numerous examples that can be cited in which these theoretical techniques are central to the accomplishment of meaningful analysis.

3. ADVANTAGES AND LIMITATIONS TO THE THEORY

The principal advantage is the ultimate confidence in predictability afforded by this type of fundamental investigation of complicated fluid flows. Other advantages are the wide scope of applicability of the theories, and the insight they furnish into the processes that are taking place. Possible disadvantages are the necessity for powerful computers to obtain solutions, and some residual uncertainties that may always be present in the moment closures for the disordered part of the turbulence. At present, however, there is little alternative to the use of theoretical techniques like those described in this presentation, in the attainment of useful results for challenging problems.

4. FUTURE DEVELOPMENTS

Strengthening the theoretical foundations is a high priority goal for the investigations. Even at this present stage the various forms of the theory need extensive exercising. The scope of applications will likely be enormous; many will produce useful results in the near future while others will require added insight or computer strength for success. Perhaps the most intriguing directions for future development lie in combining these models for instability, interpenetration, and turbulence with the additional physics of radiation transport, chemical or nuclear energy release, strange material properties, fragmentation and coalescence of particles, and the complexities of an entity-size spectrum.

5. HARDWARE/SOFTWARE REQUIREMENTS

Laboratory and field experiments for testing and verification of theoretical models will require considerable hardware, but that issue is not addressed in the present talk. Computers will need considerable memory and speed for most applications. Software requirements include the most advanced codes for numerical fluid dynamics involving large distortions, interface slippage, mesh adaptivity, multiphase interpenetration, and all the necessary capability for complicated input and display of results.

ACKNOWLEDGMENT

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The following viewgraphs were used during the talk.

TURBULENCE

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TECHNICAL FOCUS

Instability

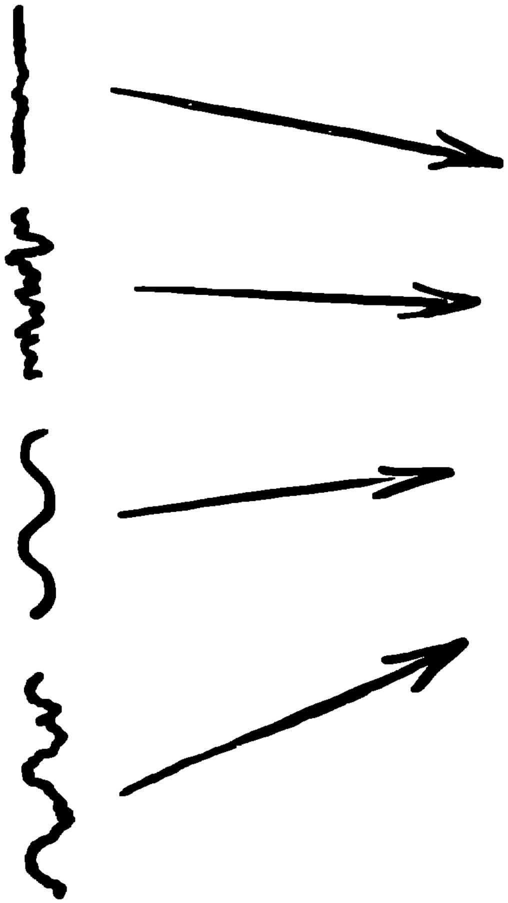
- Material interface
- Converging shock
- Burn front
- Ablation front
- Perturbation independence!

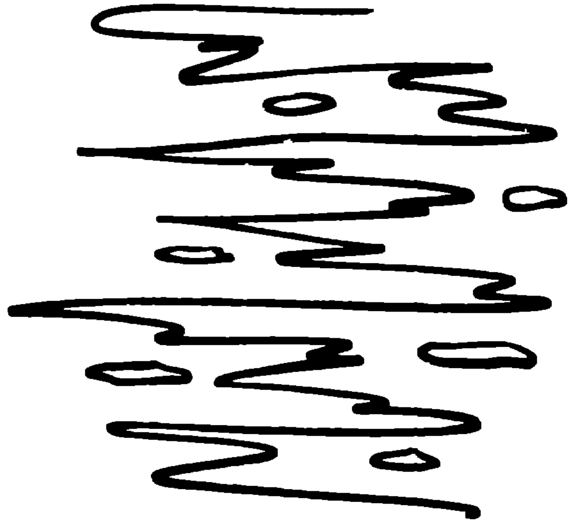
Turbulence

- Mix
- Shear impedance
- Heat dispersal

Multiphase Interpenetration

PERTURBATION INDEPENDENCE





"Order jets"

plus

turbulent diffusion

INTENSE EXPERIMENTAL ACTIVITY

Shock Tubes

- Soviet (Andronov)
- French (Limeil)
- Cal Tech
- LANL (Benjamin)

Laser-Driven

- AWRE (foils)
- French (foils and spheres)
- Livermore
- X-1 (local and Rochester)

Low-speed

- AWRE (rocket sled)

THREE THEORETICAL APPROACHES

Multifield Interpenetration

- **Cook-Demuth-Harlow**
- **Youngs**
- ***Binstock***
- **Scannapieco-Cranfill**

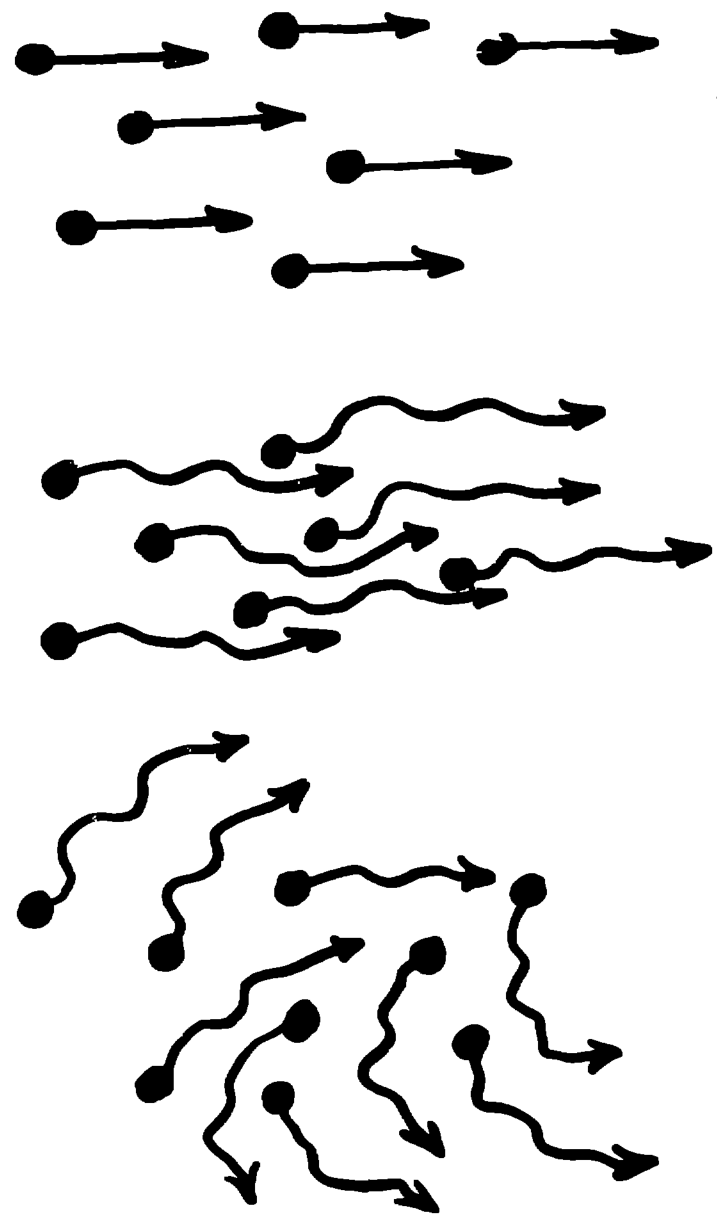
Single-Field Turbulence

- **Andronov et al.**
- **Lumley**
- **Besnard-Harlow-Rauenzahn-Janssen**
- **Leith**

Brute-Force Numerics

- **Youngs-Wareing**
- **Sharp-Glimm**

Multiphase Interpenetration



Turbulence

EFFECTS

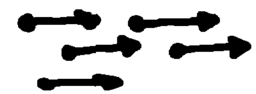
Mixing of	For Example
• Mass	Material Species
• Momentum	Shear Impedance
• Energy	Heat Dispersal

PHYSICAL PROCESSES

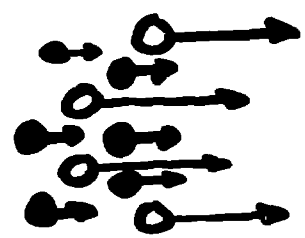
Creation of Turbulence

- **From Mean-Flow Kinetic Energy**
  - **Shear Instability (vorticity)**

  - **Interpenetration Instabilty**



- ***From Differential Acceleration***
  - **Pressure Gradients**
    - **Shocks**
    - **Rarefactions**
    - **Multiple Acoustic Waves**
    - **Centrifuging**



  - **Buoyancy**
- **From Chemical or Ablative**
  - **Surface Instability**

PHYSICAL PROCESSES

Transport

- **Mean-Flow Advection**

  displacement

  dilation

  rotation (of tensors)

- **Diffusion**

  viscous

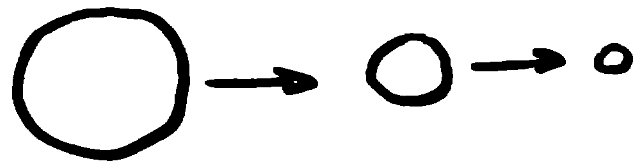
  turbulent*

***Turbulent self diffusion is non-linear!**

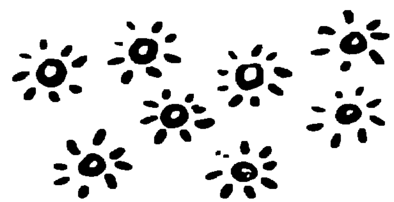
PHYSICAL PROCESSES

<u>Decay</u>

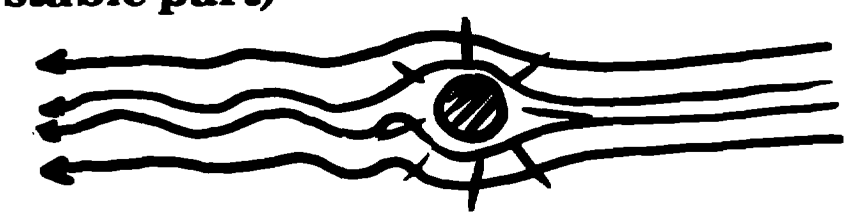
- **Cascade (large to small)**



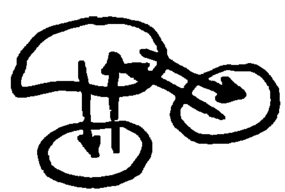
- **Viscous dissipation (small to heat)**



- **Drag (the stable part)**

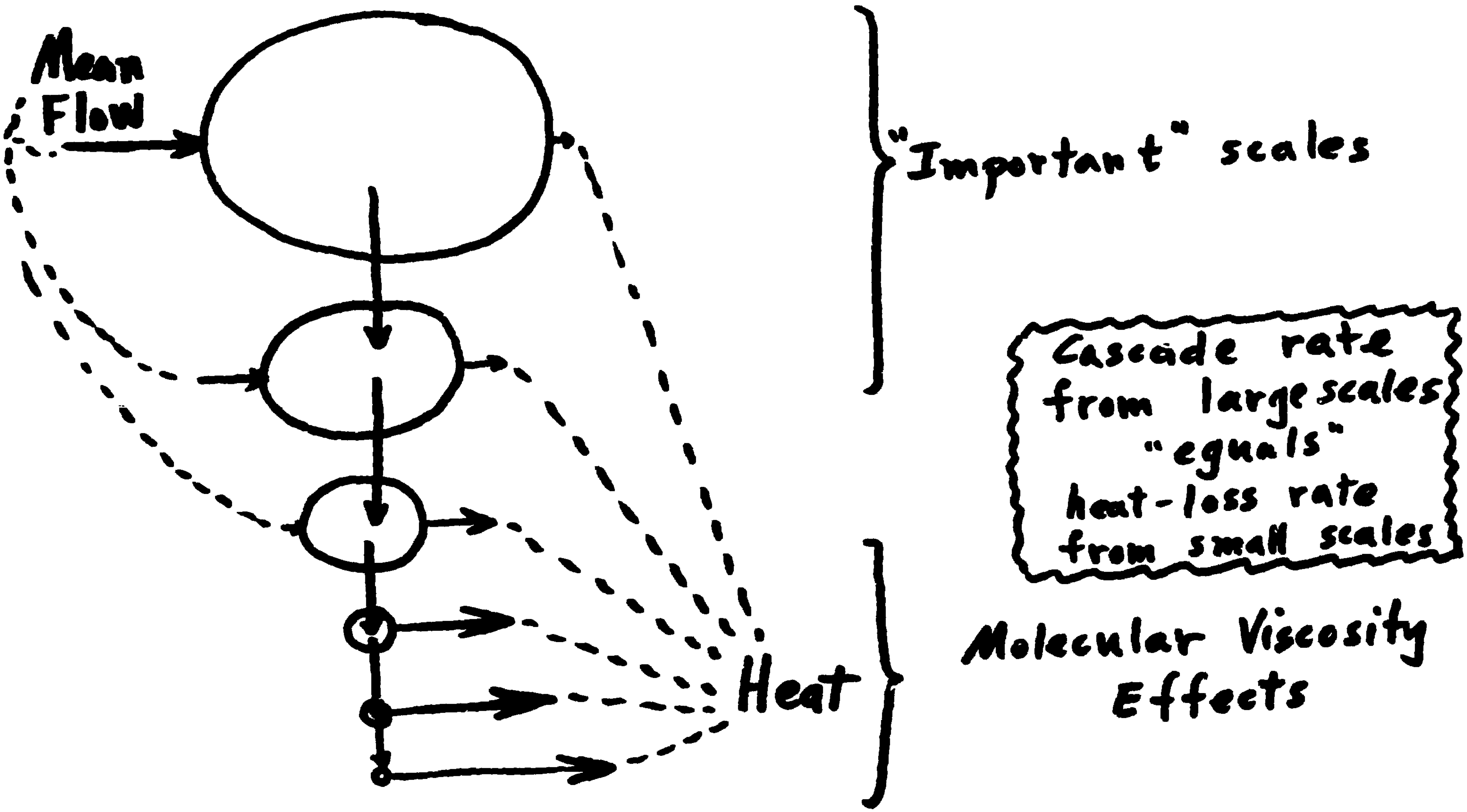


- **Eddy sharing (for decay of $\overline{\rho'\rho'}$)**



PHYSICAL PROCESSES

Summary



MATHEMATICAL DESCRIPTIONS (CURRENT)

Multiphase Flow

- Variables for each field
- Exchange Functions
- Entity Descriptions

Turbulence

- Constant Density
- Variable Density (Low Mach #)
  - Temperature variations
  - Different species
- Two-field turbulence
  - $R_{1\,ij}$ and $R_{2\,ij}$

LEVELS OF APPROXIMATION FOR TURBULENCE

- **General Non-Isotropic**
- **Isotropic Assumption**
- **Simplified Closures** $(k-\varepsilon)\begin{cases}\text{one equation form}\\ \text{two equation form}\end{cases}$
- **Point Functional (mixing length)**
- **Eddy Viscosity (variable or constant)**

A major challenge at all levels:

What is S ?

CLOSURES

for example:

$$\overline{u_i' \rho'} \equiv A_i$$ **with Transport Equation**

$$= -\frac{\alpha s}{k} R_{ij} \frac{\partial \bar{\rho}}{\partial x_j}$$

$$= -\alpha s \sqrt{k} \frac{\partial \bar{\rho}}{\partial x_i}$$

ORDERED-LIMIT GUIDANCE

<u>Multiphase</u> <u>flow</u> has unique correlation between ρ' and u_i'.

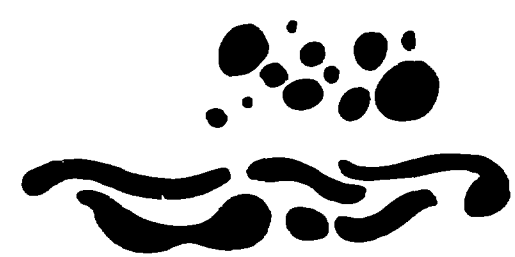
Thus

$$\overline{\rho' u_i'} \qquad \overline{\rho' u_i' u_j'}$$

can be "uniquely" calculated.

Uncertainties lie in the physics of

- entity scale variations
- entity contortions
- exchange functions



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THUS

Closure term

= (ordered fraction) (<u>ordered closure</u>)

+

(disordered fraction) (<u>turbulence closure</u>)

Where turbulence closure is

- **Derived**
  - **Point functional**
  - **Transported**

- **Postulated with "universal" constants determined empirically**